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# HANDLING AND DISPOSAL OF SLUDGES FROM COMBINED SEWER OVERFLOW TREATMENT

Phase II - Impact Assessment

by

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## FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problems, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report documents the results of an assessment of the effort that the United States will have to exert in the area of sludge handling and disposal if, in fact, full-scale treatment of combined sewer overflows is to become a reality.

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ABSTRACT

This report documents the results of an assessment of the effort that the United States will have to exert in the area of sludge handling and disposal if, in fact, full-scale treatment of combined sewer overflows (CSO) is to become a reality. The results indicate that nationwide an average yearly sludge volume of 156 x $10^6$ cu m (41.5 x $10^9$ gal.) could be expected from CSO if complete CSO treatment were achieved. This compares to a raw primary sludge volume of 60.9 x $10^6$ cu m (16.1 x $10^9$ gal.). However, the average solids concentration in CSO sludge is about 1% compared to 2-7% in raw primary sludges. This is due to the high volume, low solids residuals generated by treatment processes employing screens. The sludge volume generated and the reported characteristics of the sludge vary widely, depending on the type of treatment process used. The most notable differences from raw primary sludge were the high grit and low volatile solids content in CSO residuals plus their intermittent generation.

Evaluation of the effect of bleed/pump-back of CSO sludge on the hydraulic, solids and/or organic loadings to the dry-weather plant indicated that overloading would occur in most instances. Disregarding grit accumulation in sewers plus other transport problems, it was established that solids loadings to the secondary clarifier were limiting and required 8-22 day bleed/pump-back periods. There may also be a toxic danger to dry-weather treatment plant biological processes.

The most promising treatment trains were found to include possible grit removal, lime stabilization, optional gravity thickening, optional dewatering and land application or landfill. Land application systems can be considered as viable alternatives for CSO treatment and disposal. The cost of the collection-transportation and/or equalization system may be the crucial factor in disallowing the alternative of direct application of raw CSO. If CSO treatment is employed by a city, land spreading of CSO sludges should be evaluated. Public health concerns dictate sludge stabilization before disposal and pollutant loading limitations based on nitrogen and heavy metal concentrations. An environmentally safe rate of application was determined as 19.0 metric tons/ha/yr (8.5 tons/ac/yr).

Preliminary economic evaluation indicated that lime stabilization, storage, gravity thickening, and land application was the most cost-effective treatment system. Costs for overall CSO sludge handling depend on the type of CSO treatment process, volume and characteristics of the sludge and the size of the CSO area, among other considerations. Estimates indicate that first investment capital costs range from $447-10,173/ha ($181-4129/ac) with annual costs of $139-1630/ha ($56-660/ac). It is recommended that the use of grit removal, lime stabilization and gravity thickening, plus dewatering, be further investigated to establish specific design criteria related to CSO sludge.

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SECTION I

CONCLUSIONS

1. Nature of the Problem

   a. It is established that 33 percent of the sewered population or approximately $36.2 \times 10^6$ people are served by combined sewers. This service is approximately $1.23 \times 10^6$ ha ($3.03 \times 10^6$ acres) and is mainly concentrated in the Northeast and Great Lakes regions of the country.

   b. Assuming an average annual rainfall of 91.4 cm (36 in.) and that 50 percent of the rainfall results in overflow, then the yearly combined sewer overflow (CSO) is $5.\bar{6} \times 10^9$ cu m ($1.5 \times 10^{12}$ gal.).

      Similarly, the annual dry weather flow for the combined sewer population served is $6.3 \times 10^9$ cu m ($1.7 \times 10^{12}$ gal.), assuming 473 ℓ (125 gal.) per capita per day.

   c. The volume of sludge generated from CSO treatment is dependent upon many factors including area served, rainfall and type of CSO treatment method used. The sludge volume generated will range from 0.6 to 6 percent of the CSO volume treated, depending on the CSO treatment process utilized.

   d. There have been six state-of-the-art processes proposed for treating combined sewer overflows. If it is assumed that the total combined sewer overflow volume is treated by each technique, the following volumes and solids concentrations of CSO residuals may be estimated, assuming 70 percent solids removal:

      storage-sedimentation: $50.4 \times 10^6$ cu m ($13.3 \times 10^9$ gal.), 1.7% solids
      microscreening: $336 \times 10^6$ cu m ($88.8 \times 10^9$ gal.), 0.7% solids
      screening/dissolved air flotation: $268 \times 10^6$ cu m ($71.1 \times 10^9$ gal.), 0.84% solids
      dissolved air flotation: $33.6 \times 10^6$ cu m ($8.8 \times 10^9$ gal.), 2.75% solids
      contact stabilization: $196.1 \times 10^6$ cu m ($51.8 \times 10^9$ gal.), 1.0% solids
      trickling filtration: $39.2 \times 10^6$ cu m ($10.3 \times 10^9$ gal.), 3.2% solids

e. The average yearly volume of CSO sludge is estimated to be 156 x $10^6$ cu m (41.5 x $10^9$ gal.) compared to an annual primary sludge volume of 60.9 x $10^6$ cu m (16.2 x $10^9$ gal.). However, the average percent solids in CSO sludge is 1.04 percent compared to a primary sludge with 2-7 percent solids. The low value for CSO sludge can be attributed to the high volume-low solids residuals generated by backwash of the screening processes used.

f. Comparison of per capita CSO sludge values with the per capita dry weather values over a 365 days per year period indicates that the values are comparable. However, the magnitude of the CSO disposal problem on a per unit time basis is six times greater when it is recognized that overflows occur only 60 times per year.

g. The characteristics of CSO sludges vary widely depending upon the CSO treatment method utilized. A comparison of quality with dry weather primary sludges indicates that the volatile solids content of CSO sludge is significantly lower than that found in most primary sludge. In other parameters, the ranges of reported values overlapped. Generally, nutrient concentrations and fecal coliform counts were lower for CSO sludges than for raw primary sludges. Metal concentrations varied widely; however, in general, nickel concentrations were higher and lead concentrations were lower in CSO sludges compared to raw primary.

h. Differences in CSO sludge characteristics compared to dry-weather sludge most pertinent to further handling are the high grit and low volatile sludge concentration, the lower average percent solids, the variable volume of sludges produced and their intermittent generation.

2. *Alternatives for Handling and Disposal of CSO Generated Residues*

Alternatives for handling CSO treatment sludges include (a) bleed/pump-back to the dry-weather facilities, (b) dewatering at parallel facilities at the dry-weather plant or at central facilities separate from the dry-weather plant and (c) dewatering at on-site facilities.

a. Bleed/pump-back of CSO treatment sludges to the dry-weather facilities.
   (1) The more excess capacity available at the dry-weather plant, due to built-in safety factors for expansion, the more feasible bleed/pump-back of CSO sludges.
   (2) This procedure would involve the lowest costs due to reduced transportation and use of existing dry-weather facilities for handling. However, this alternative has inherent disadvantages which make the procedure generally not applicable.
   (3) Bleed/pump-back will not be possible unless sufficient scouring velocity can exist in the individual sewer interceptors to prevent accumulation of grit in the lines. Excessive grit deposition in the sewer can cause odor, septicity, and blockage problems and if flushed to the plant, adversely affect normal operation.

(4) The bleed/pump-back of CSO sludges or the residuals from on-site dewatering will have an effect both on the dry-weather treatment plant and the sludge handling facilities. These impacts can be considered separately.

(5) Impact of bleed/pump-back of CSO sludges on the dry-weather treatment plant has been evaluated with respect to hydraulic, solids (primary and secondary), organic and toxic materials loadings to the various processes. Bleed/pump-back of the sludge over a 24 hour period although desirable from a standpoint of limited storage and reduction in septicity, is not possible in most instances.

(6) The limiting factor to consider is the solids loading to the final clarifier. Calculations indicate that bleed/pump-back periods of 8-22 days are necessary depending upon the CSO treatment method involved.

(7) Bleed/pump-back of CSO treatment sludges directly to the dry-weather sludge handling facilities over a 24 hour period will overwhelmingly overload these facilities hydraulically, solids wise and organically. These gross overloads will be expected to detrimentally affect the dewatering and stabilization performance and treatment efficiency of the dry-weather sludge handling facilities. The down-grading in treatment efficiency would be manifested in poorly stabilized sludge for disposal and grossly deteriorated thickener effluents, filtrates, supernatants, etc. for recirculation back to the dry weather treatment plant.

(8) Disadvantages of bleed/pump-back also include the adverse effect on the operation and efficiency of the dry-weather plant caused by loading the plant at excessive levels constantly and the difficulty in storing CSO residuals without stabilization for any excessive length of time.

b. Dewatering CSO treatment sludges at parallel facilities at the dry-weather plant or at central facilities separate from the dry-weather plant.

(1) Transportation and potential space problems limit the applicability of parallel facilities or central locations.

c. Dewatering at on-site Facilities.

Handling of CSO treatment sludges in the dry-weather plant or in additional parallel facilities at the dry-weather plant or in separate facilities at the dry-weather plant do not appear to be generally feasible, therefore it is indicated that CSO sludges will have to be treated separately at the on-site facilities.

(1) Evaluation of sludge handling processes from the standpoint of the high grit and low volatile content of CSO sludges along with the variable and intermittent generation reduces the number of processes applicable for CSO sludge handling.

(2) Preliminary screening on the basis of CSO sludge characteristics and known information about the processes, indicates that the

following processes may be generally applicable:

| | |
|---|---|
| conditioning: | chemical treatment |
| thickening: | gravity thickening |
| stabilization: | lime stabilization |
| | anaerobic digestion |
| dewatering: | vacuum filtration |
| | centrifugation |
| disposal: | land application |
| | landfill |

(3) Combinations of the above processes yields approximately ten potential treatment schemes. Examination indicated that bleed/pump-back of dilute residuals from on-site dewatering to the dry-weather plant appears to be practical and warrants further consideration where applicable.

Further evaluation of stabilization techniques indicates that anaerobic digestion is more costly and difficult to operate than lime stabilization and therefore this process was not considered for further study.

(4) Four sludge handling alternatives were then developed for CSO sludge handling:

(a) Lime stabilization → gravity thickening → vacuum filtration → landfill
(b) Lime stabilization → gravity thickening → vacuum filtration → land application
(c) Lime stabilization → gravity thickening → land application
(d) Lime stabilization → land application

Preliminary indications are that the flow scheme utilizing lime stabilization plus gravity thickening and then land application is the most cost effective for CSO sludge handling on a generalized basis.

(5) The logistics of operating and maintaining multiple CSO solids handling plants (5,10,100) at different locations throughout a city are formidable but not insurmountable. Similar, if not greater logistics would be required for multiple CSO treatment facilities from which the sludges to be handled are derived.

3. Costs for Handling and Disposing of CSO Generated Sludges.

It is emphasized that all costs presented are generalized and should not be applied to individual situations.

a. To establish generalized CSO sludge impact, the cities served by combined sewers were evaluated. Of the total 259 cites, it was found that about 12.5 percent had CSO areas of 405 ha (1000 ac) or less, 47.5 percent had areas from 405-4050 ha (1000-10000 ac), 35 percent had CSO area from 4050-16,188 ha (10000-40 000 ac) and about 5 percent had larger areas. From this information, four generalized CSO areas were chosen for further cost evaluation.

b. The generalized costs for CSO sludge satellite treatment assuming 50 percent of rainfall is CSO and that either contact stabilization or dissolved-air flotation was used for treatment, are presented below:

| CSO area | | Annual Cost ($) | $/acre/yr |
|---|---|---|---|
| ha | acres | | |
| 203 | 500 | $0.105 - 0.330 \times 10^6$ | 210 - 660 |
| 2,307 | 5,700 | $0.36 - 1.96 \times 10^6$ | 64 - 345 |
| 10,118 | 25,000 | $2.24 - 10.38 \times 10^6$ | 77 - 415 |
| 24,282 | 60,000 | $3.33 - 26.1 \times 10^6$ | 56 - 435 |

c. For four example cities, cost estimates were prepared for handling and disposing of their sludges if complete CSO treatment is achieved (for New Providence the cost is for treating increased sanitary sewer flows due to wet weather sewer infiltrations). The four treatment schematics [see Conclusion 2.c.(4)] were evaluated and a cost range is included.

| City | CSO area | | Annual Cost (range) |
|---|---|---|---|
| | ha | ac | |
| Milwaukee, WI | 7,006 | 17,300 | $\$1.49 - 2.53 \times 10^6$ |
| San Francisco | 12,150 | 30,000 | $\$1.19 - 2.11 \times 10^6$ |
| Kenosha, WI | 539 | 1,331 | $\$0.21 - 0.46 \times 10^6$ |
| New Providence, NJ | 0 | 0 | $\$0.09 - 0.15 \times 10^6$ |

d. The economic impact of treating CSO sludges nationwide using one of the treatment systems evaluated would range from $\$169 \times 10^6$ - $\$1,720 \times 10^9$ annually with initial capital costs estimated to range from $\$548 \times 10^6$ - $\$12.5 \times 10^9$.

4. Land Application for Disposal of CSO Raw Waste and of CSO Treatment Sludges.

a. General

(1) Land application systems can be considered as viable alternatives for waste treatment and disposal. The feasibility of land application of CSO wastes may be evaluated under various conditions. This development would provide a rational screening method which should lead to; 1) the identification of

specific limiting factors, 2) an indication of the public health and legal constraints in using land application and 3) site locations that combine the required characteristics for safe pollutant management.

(2) For most land application systems, vast numbers of design possibilities are available to suit specific site characteristics, treatment requirements and overall project objectives. The scope of factors that are commonly considered in the design process include: a) preapplication treatment requirements; b) storage requirements; c) climatic factors; d) pollutional loading constraints: e) land area requirements; f) crop selection and management; g) system components; h) site monitoring program; and i) cost-effectiveness.

b. Handling CSO Raw Waste

(1) An alternative to the treatment of CSO and the resultant problems of sludge handling and disposal is direct application of the raw CSO to the land. Land area requirements necessary for a safe rate of application, as controlled by liquid loading limitations, are $34.4 \times 10^6$ ℓ of CSO/ha/yr ($3.6 \times 10^6$ gal./ac/yr).

(2) The cost of the collection - transport and/or equalization system may be the crucial factor in disallowing land disposal of raw CSO as an alternative to other CSO treatment methods. It may be feasible to use land disposal in cities which have relatively small CSO areas and have land available in close proximity to the city, but cities with large CSO areas, even if the land is available, may find that the cost of the collection - transport system might be prohibitive.

(3) Considering the hydraulic loading limit and if the land required for actual disposal is 70 percent of the entire disposal site, nationwide disposal of raw CSO would require a total land area of 323,560 ha (587,300 acres), inclusive of that required for buffer zones and storage and pre-treatment facilities.

c. Handling CSO Treatment Sludges

(1) If CSO treatment is employed by a city, one viable alternative to the disposal of CSO sludges can be by landspreading application. Three management options would be available: 1) landspreading a dilute sludge (1% solids); 2) landspreading a thickened sludge (4-6% solids) and 3) landspreading a dewatered sludge (>12% solids).

(2) If regulations require CSO sludges to be treated prior to land application, lime stabilization appears to be a promising

preapplication treatment process because of its flexibility and effectiveness, in terms of both cost and performance.

(3) In transporting CSO sludges, it appears that truck transportation of either liquid or dewatered sludge is the most desirable alternative in CSO areas with significant volumes of sludge to be handled. Truck transportation of dewatered sludges might prove to be the more desirable alternative if transporting and storing costs are greater than the additional thickening-dewatering costs.

(4) For field area requirements, the nitrogen content is the limiting loading factor for application of CSO sludges. An environmentally safe rate of application was assumed as 18.9 metric tons/ha/yr (8.5 tons/ac/yr). This is lower than the average range of 22 to 45 metric tons/ha/yr (10-20 tons/acre/yr) reported in the literature for disposal of municipal sludges. This discrepancy is a result of differences in waste characteristics (i.e. nutrients and metals).

(5) For sludge application to non-agricultural lands (e.g. strip mine reclamation), higher loading rates may be allowable but the migration of pollutants through the soil must be closely monitored.

(6) Considering the loading limit established for nitrogen and the fact that, on the average, the land required for actual disposal is 70 percent of a disposal site; nationwide disposal of CSO sludges would require 117,760 ha (290,760 acres) of land, including that required for buffer zones and pre-treatment facilities.

## SECTION II

## RECOMMENDATIONS

1. A CSO sludge treatment system consisting of nonvolatile solids removal, lime stabilization, gravity thickening, optional sludge dewatering and land application appears promising. However, since several aspects are experimental, it is recommended that the swirl concentrator and or other suitably available equipment be assessed with respect to its applicability for grit removal from CSO sludges and further investigation and demonstration of lime stabilization for application to CSO sludges and to establish basic design and operating criteria be pursued. In addition, the applicability of further thickening and dewatering be investigated to establish feasibility and obtain basic design criteria.

2. It is recommended that further information on the effect of lime on sludges which may be applied to land be established. Particular attention should be given to the effect on crop growth, physical characteristics of the soil and uptake of toxic materials. This information can then be utilized to modify current design criteria for land application of CSO sludges.

## SECTION III

## INTRODUCTION

The discharge of untreated sanitary and stormwater overflows from combined sewers to receiving waters during and after heavy rains is an important source of impairment of water. These storm generated discharges constitute a high degree of pollutional load to water courses as measured by the usual standards of biochemical oxygen demand, solids, coliform organisms, and nutrients.

The pollutional contribution of storm generated discharges is of national significance, and the magnitude of the problem is illustrated by the fact that more than 1300 U.S. communities serving 36.2 million people have combined sewer systems which provide one collection system for both sanitary sewage and stormwater runoff (1). Sufficient information has been accumulated to confirm that the combined sewer overflow problem is of major importance and is growing worse with increasing urbanization, economic expansion, and water demands (1,2,9).

Various alternatives have been proposed for dealing with the problems of storm generated discharges. There appear to be four possible methods of eliminating or minimizing the problems. These are:

1. Construction of larger interception sewers and expansion of treatment capacity.
2. Construction of separate sewers.
3. Construction of holding tanks with provisions to bleed/pump-back flows into the sewer system after the storm.
4. Treatment of the storm generated discharges at various possible locations.

Each of these techniques has advantages and disadvantages when utilized for CSO abatement at individual locations. Construction of larger interceptors throughout the country appears to be a formidable undertaking. Normal design capacity for interceptors is between 1.5 and 5.0 times the dry weather flow (3)(4). During a storm, the flow in a combined sewer may increase from 50 to 100 times the dry weather flow (3). It is apparent that enlarging the interceptors to handle the great increase in anticipated stormwater flow will have to be accompanied by enlargement of present sewage treatment plants which must treat the interceptor flow. The cost of this construction undertaking would be in the multibillion dollar range. In addition, there are monetary losses which would have to be borne by communities, individuals, businesses and industrial establishments as a result of extensive physical inconveniences occuring during construction.

It has been estimated that providing complete separation of storm and sanitary sewers throughout the country would cost 48 billion dollars (1967 prices)(1). In addition, the monetary losses to communities, individuals, etc. as a result of separation would be considerable. Separation of the sewers may not completely solve the problem, for studies indicate that there is the distinct probability that separated stormwater may require treatment under some circumstances (9).

The holding tank concept is being used as a method of handling storm generated discharges. This method has met with limited success because of the cost of tank installation, the economic and physical limitations of holding capacity, and the need for returning the flow to the interceptor system for treatment after the storm subsides. In many locations, an overloaded condition exists at the treatment plant for several days after a major runoff event and any additional runoff in excess of holding tank capacity is discharged to the receiving waters.

The fourth alternative for dealing with storm generated discharges is the treatment of the discharge itself. Promising physical, physical-chemical, and biological methods have been proposed for treating storm generated discharges. Many of these concepts have been demonstrated or are planned for demonstration by the U.S. Environmental Protection Agency (5,6,7).

As with most wastewater treatment processes, treatment of combined sewer overflow will result in residuals which contain, in concentrated form, the objectionable contaminants present in the raw combined sewer overflow. However, handling the disposal of the residual sludges from the combined sewer overflow treatment systems have been generally neglected, thus far, in favor of the problems associated with the treatment of the discharge itself. Sludge handling and disposal should be considered an integral part of the combined sewer overflow treatment because it will significantly affect the efficiency and cost of the total treatment system.

The objective of this report, then, is to attempt a rough quantification of the effort the United States will have to exert in the future, in the area of sludge handling and disposal, if full-scale treatment of combined sewer overflow is to become a reality. The results of this report will contribute to a better understanding of the problem and will aid in the development of future planning and research needs. It may be found, in fact, that the potential problem of handling the sludges from combined sewer overflow treatment may be greater than the problem of treatment itself. Also, the disposal of these residual solids is only going to compound the disposal problem now caused by the solids from dry-weather treatment plants.

Therefore, alternative techniques for handling combined sewer overflow sludges have been presented in this report. The first section defines the magnitude of the problems associated with combined sewer overflow treatment residuals and the unique characteristics of the sludge itself. After the problem has been defined, several handling methods are identified and evaluated. One method involves bleed/pump-back of the CSO sludge to the dry-weather treatment plant. This technique has the advantage of utilizing existing transportation systems, but has inherent difficulties such as grit deposition and potential solids overload at the treatment plant. If bleed/ pump-back is not feasible, then the sludge must be treated with separate facilities. These facilities may be located at the dry-weather treatment plant, at a separate central location or at satellite locations throughout the area served by combined sewers. Evaluation of the existing sludge handling processes indicate that traditional solids treatment trains may not be generally applicable due to the different characteristics and intermittent nature of the CSO sludge. However, the use of lime for stabilization, plus thickening and possibly dewatering, and then land application for disposal appears to be a viable treatment system for CSO sludges. The economics of various treatment schemes for both actual cities and specific CSO areas have been calculated and are presented. In this way, the magnitude of the problem can be defined and a preliminary assessment of the impact can be made.

## SECTION IV

## MAGNITUDES AND CHARACTERISTICS OF SLUDGES PRODUCED BY NATIONWIDE TREATMENT OF COMBINED SEWER OVERFLOWS

### INTRODUCTION

The problems associated with treatment or handling of any type of sludge are formidable. The recent increased emphasis on sludge handling has created more interest in this aspect of wastewater treatment. With regard to treatment of combined sewer overflow sludges, however, the most feasible handling techniques are just beginning to be developed. Before the problem can be adequately addressed, it is beneficial to define, as much as possible, the volumes of sludges to be produced and their associated characteristics. To do this, it is necessary to make general assumptions regarding many aspects of CSO treatment systems. But it must be emphasized at this point that the characteristics and flow volumes presented herein are generalizations and do not reflect individual CSO sludge systems. Definition of qualities and quantities of sludges resulting from individual processes is dependent upon the treatment system utilized, pretreatment and location of the CSO site, among many other factors. Specific applications and design of sludge handling techniques should be developed individually for each site. However, for the purpose of defining the magnitude and severity of the problems associated with handling various CSO sludges, a basic overall approach is necessary. The ranges of values for CSO sludges have also been compared to generalized dry-weather sludge volumes and characteristics. The basis for the generalizations and the result of the quantifications have been included in this section of the report.

### COMBINED SEWER OVERFLOW VOLUMES

In order to estimate the total volume of combined sewer overflow and its associated sludges, it is necessary to establish many variables which affect CSO before it is possible to accurately assess the overall situation. Among the pertinent considerations are: the area served by combined sewers; land use; rainfall volumes; number of overflows; type of treatment utilized; population of area; etc. It is necessary to evaluate the effect of these, and other pertinent variables, in order to prepare a generalized potential volume of CSO and associated sludges.

The sewered population of the United States as projected from 1962 data is 125,770,000 (1). Of this total, 36,236,000 or 29 percent of the sewered population is served by combined sewers. The combined sewer service area totals 1,226,745 ha (3,029,000 acres) (1). Figure 1 shows the distribution of combined sewers throughout the United States (10). It can be seen that the most concentrated use of combined sewers is in the Northeast and Great Lakes regions of the country.

Figure 2 shows the distribution of the median annual precipitation throughout the United States (11). The annual median precipitation across the Northeast and Great Lakes regions of the country where combined sewers are used extensively ranges from 63.5 to 114.3 cm (25-45 in.). A selected average value for the purpose of further calculations is 91.4 cm (36 in.).

Using 1,226,745 ha (3,029,000 acres), an average yearly rainfall of 91.4 cm (36 in.) and assuming 50 percent of the rainfall results in overflow, the yearly volume of combined sewer overflow in the United States would be $5.6 \times 10^9$ cu m ($1.5 \times 10^{12}$ gal.).

Table 1 gives the sludge volumes produced, the percent solids of the sludges produced by various combined sewer overflow treatment processes that have been investigated (12), and the calculated sludge volume if treated by the selected CSO treatment processes based on a total yearly combined sewer overflow volume of $5.6 \times 10^9$ cu m ($1.5 \times 10^{12}$ gal.).

TABLE 1. TOTAL U.S. SLUDGE VOLUMES AND PERCENT SLUDGE SOLIDS PRODUCED BY VARIOUS CSO TREATMENT PROCESSES (12)

| Treatment process | Volume of sludge as percent of volume treated | Sludge percent solids | Sludge volumes produced cu m |
|---|---|---|---|
| Storage with settling | 0.3 | 1.74 | $50.4 \times 10^6$ |
| Microscreening | 6.0 | 0.70 | $336.2 \times 10^6$ |
| Screening/dissolved-air flotation | 4.8 | 0.84 | $269.0 \times 10^6$ |
| Dissolved-air flotation | 0.6 | 2.75 | $33.6 \times 10^6$ |
| Contact stabilization | 3.5 | 1.00 | $196.1 \times 10^6$ |
| Trickling filter | 0.7 | 3.20 | $39.2 \times 10^6$ |

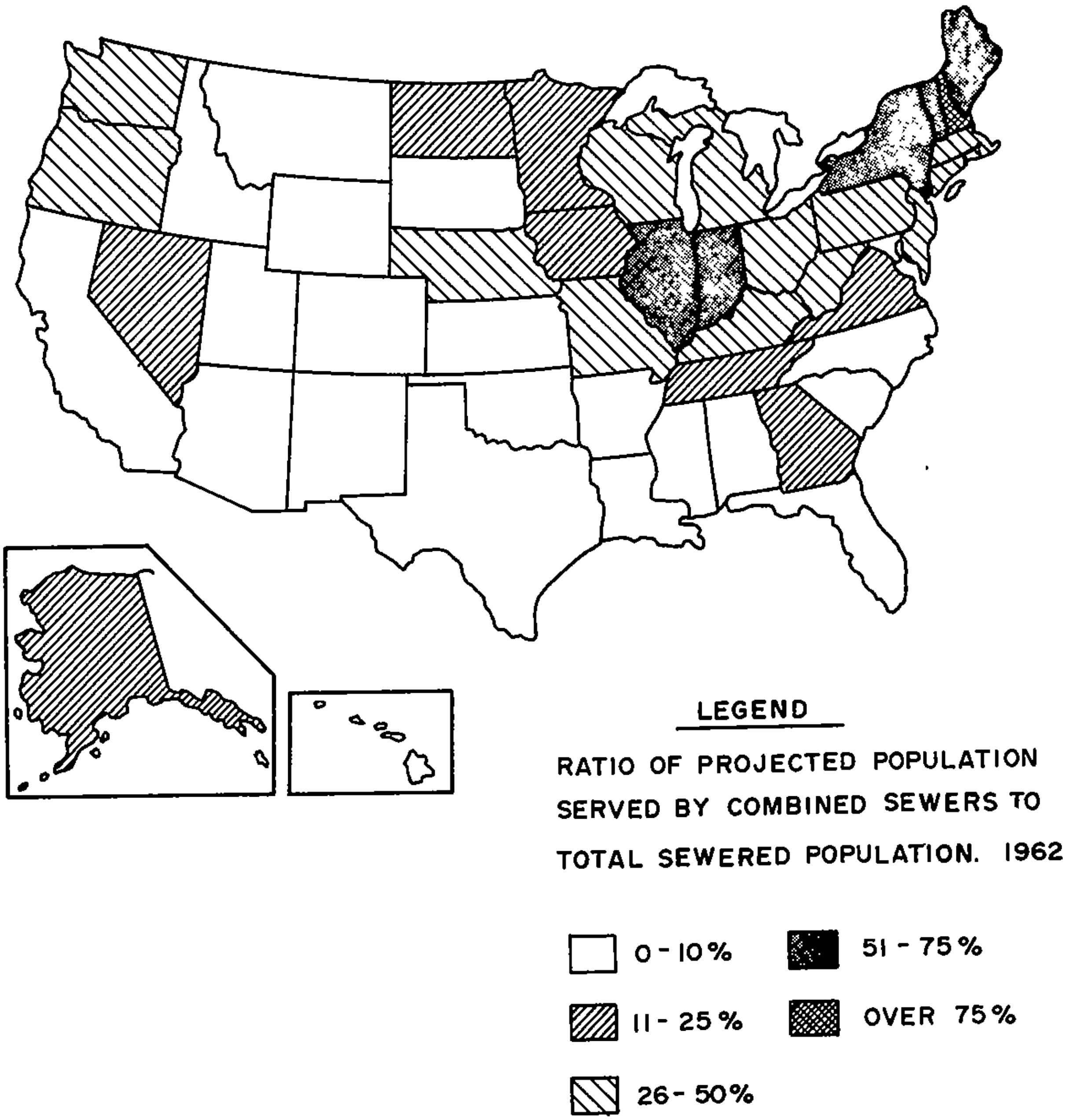


**Figure 1. Relative use of combined sewers by states (10).**

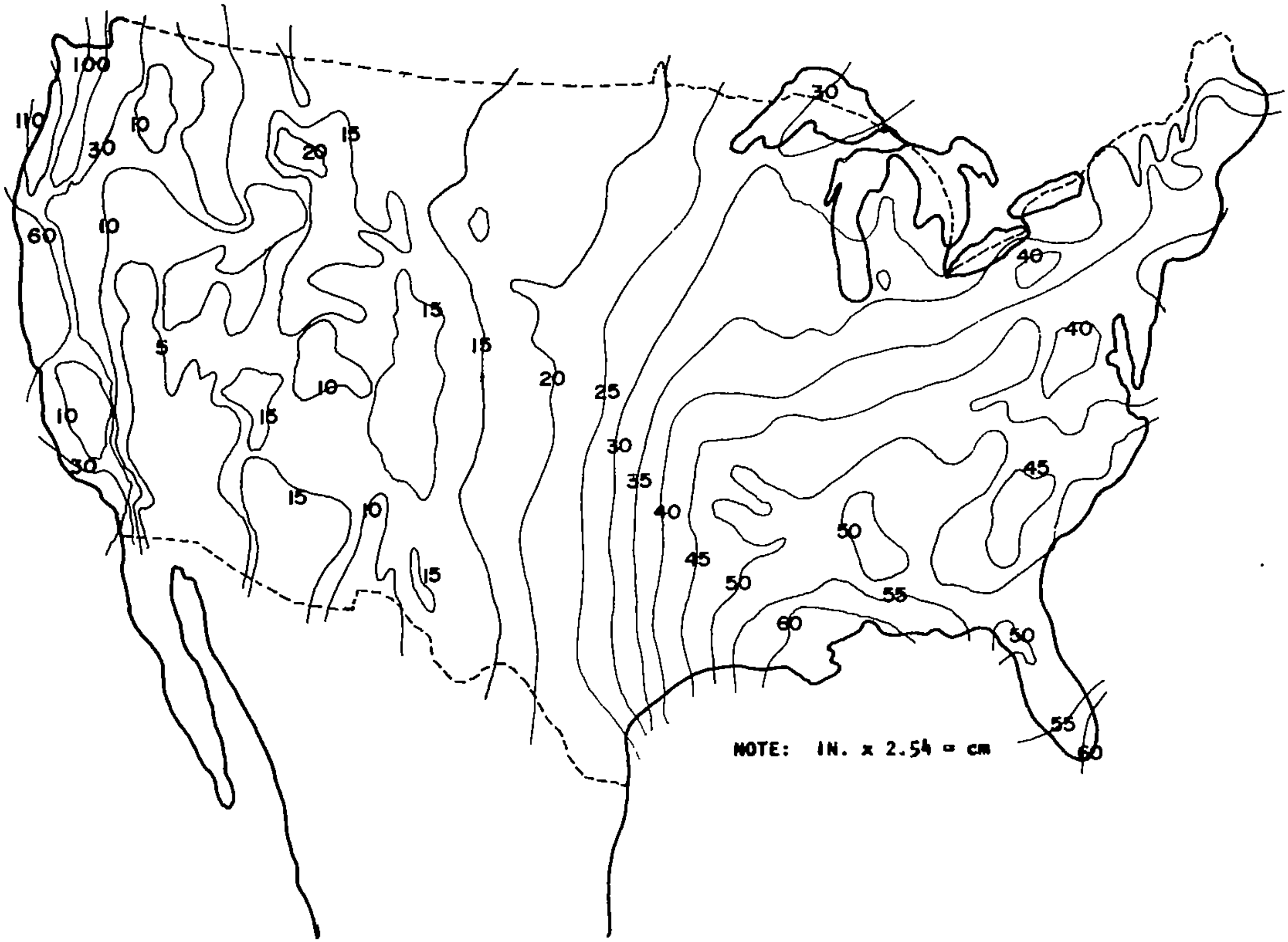


Figure 2. United States median annual precipitation (11).

Assuming an equal mix of the various treatment methods, an average yearly sludge volume resulting from treatment of all combined sewer overflows nationwide would be $156.8 \times 10^6$ cu m ($41.45 \times 10^9$ gal.), or 2.8 percent of the volume treated. The average percent solids of the sludge would be 1.04. This value compared to an estimated 125,000,000 cu m ($33.0 \times 10^9$ gal.) of primary and secondary sludges generated annually (13). The average solids concentration of the dry-weather sludge is approximately 2-3%. The average value for CSO sludge solids concentration is lower because of the high volume - low solids residuals that are generated by the screening processes, microscreening (6% of volume treated at 0.7% solids) and screening/dissolved-air flotation (4.8% of the volume treated at 0.84% solids).

Another approach to comparison of dry-weather sludge and wet weather sludge is to use population equivalent factors. Table 2 shows a comparison between total flow, sludge volume and solids mass based on the population served.

TABLE 2. POPULATION EQUIVALENT COMPARISONS (14)

| Parameter | Units | Dry-weather population equivalent | CSO 365 days/yr | CSO 60 days/yr |
|---|---|---|---|---|
| Flow: raw waste | gal./capita-day | 125 | 111 | 679 |
| Flow: sludge only | gal./capita-day | 2.65 | 3.10 | 18.90 |
| Solids loading | lb/capita-day | 0.44 | 0.27 | 1.64 |

gal. x 3.785 = ℓ
lb x 0.454 = kg

As can be seen the population equivalents for CSO sludge are approximately equal to that for dry-weather treatment plant design when considered on the basis of 365 days per year. However, the average number of combined sewer overflows annually is 60 so that the actual loading is more than six times greater than typical design data.

The preceding calculations were based on the sludge volume and solids data reported for the various processes in the literature (12). On the average, the processes achieved a suspended solids (SS) removal of 70 percent. Differences in the removal efficiences and/or the sludge concentrations produced will result in corresponding changes in the final sludge volumes. Table 3 shows the different sludge volumes that will be generated at varying treatment efficiences and sludge concentrations if the nationwide combined sewer

TABLE 3. CSO SLUDGE VOLUMES FOR VARYING TREATMENT EFFICIENCIES AND SLUDGE CONCENTRATIONS

Volume Treated = $5.6 \times 10^{9}$ cu m ($1.5 \times 10^{12}$ gal./year)
Influent SS = 409 mg/l

| Percent SS removal achieved | Sludge volume produced at: | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.5% solids | | 1.0% solids | | 2.0% solids | | 3.0% solids | |
| | cu m x $10^{-6}$ | MGx$10^{-3}$ | cu m x $10^{-6}$ | MGx$10^{-3}$ | cu m x $10^{-6}$ | MGx$10^{-3}$ | cu m x $10^{-6}$ | MGx$10^{-3}$ |
| 50 | 228.6 | ( 60.4) | 114.3 | (30.2) | 57.2 | (15.1) | 38.2 | (10.1) |
| 55 | 252.1 | ( 66.6) | 126.0 | (33.3) | 63.2 | (16.7) | 42.0 | (11.1) |
| 60 | 274.4 | ( 72.5) | 137.4 | (36.3) | 68.5 | (18.1) | 45.8 | (12.1) |
| 65 | 298.3 | ( 78.8) | 149.1 | (39.4) | 74.6 | (19.7) | 49.6 | (13.1) |
| 70 | 320.5 | ( 84.7) | 160.1 | (42.3) | 79.9 | (21.1) | 53.4 | (14.1) |
| 75 | 344.0 | ( 90.9) | 171.8 | (45.4) | 85.9 | (22.7) | 57.2 | (15.1) |
| 80 | 366.4 | ( 96.8) | 183.2 | (48.4) | 91.6 | (24.2) | 60.9 | (16.1) |
| 85 | 389.9 | (103.0) | 195.0 | (51.5) | 97.7 | (25.8) | 65.1 | (17.2) |
| 90 | 412.5 | (109.0) | 205.9 | (54.4) | 102.9 | (27.2) | 68.9 | (18.2) |
| 95 | 436.0 | (115.2) | 218.0 | (57.6) | 109.0 | (28.8) | 72.7 | (19.2) |

overflow volume is treated. The values are based on an average combined sewer overflow SS concentration of 409 mg/l (9); and it should also be noted that the volumes are based on the SS removal. Biological treatment methods such as contact stabilization and trickling filters will also produce solids by conversion of dissolved organic matter to biological cell mass; and any chemical addition that is employed in the selected treatment process will also add solids. These additional solids can increase the final sludge volume.

From Table 3, it can be seen that as the treatment efficiency is improved the volume of sludge that must be handled will increase. However, whenever a thicker sludge can be produced the residual sludge volume will be reduced.

CSO TREATMENT SLUDGE CHARACTERISTICS

There are significant differences in the chemical and physical characteristics of sludges which are generated by various CSO treatment methods. Tables 4, 5 and 6 (12) indicate the reported sludge characteristics from biological, physical and chemical treatment systems. Even within these more specific categories, there are large differences in the qualities which result.

Biological treatment sludges show the highest volatile fraction, about 60 percent, while the physical and physical/chemical treatment processes produce sludges with a 25 to 48 percent volatile fraction. The BOD, total organic carbon, dissolved organic carbon, total phosphorus, and total Kjeldahl nitrogen concentrations vary widely as the solids concentrations vary. The soluble nitrogen forms; ammonia, nitrites, and nitrates, are, for the most part, low in concentration except for the trickling filter secondary sludge which has a very high content. The sludge densities range from 1.005 to 1.07 with an average value of 1.026. The pH of the sludges ranges from 5.2 to 7.9. The low value of 5.2 was found for the dissolved-air flotation process in San Francisco where alum addition is used to facilitate the flotation process. As would be expected with higher volatile solids, the biological sludges have the greatest fuel values. The biological sludges have an average fuel value of 3515 cal/gm (6333 BTU/lb) while the other sludges have an average value of 2032 cal/gm (3661 BTU/lb). Among the PCB's and various pesticides, the PCB's are generally of the highest concentration. Zinc is usually the heavy metal of highest concentration in the sludges, with the concentration of lead also being fairly high.

COMPARISON OF CSO SLUDGES TO DRY-WEATHER FLOW SLUDGES

In order to more fully understand both the magnitude and the uniqueness of the problems associated with treatment and handling of CSO sludges, it is valuable to compare CSO sludges to dry-weather flow sludges. The most direct comparison which can be drawn is between undigested primary sludge and CSO sludge. Although the solids concentration of waste activated sludge most closely resemble CSO sludge solids concentrations, the actual biomass characteristics are different since grit removal and primary sedimentation have preceded the process and removed the more easily separated materials. These

TABLE 4. CHARACTERISTICS OF CSO SLUDGES FROM PHYSICAL TREATMENT PROCESSES (12)

| Parameter | Units | Storage sedimentation (Milwaukee, WI) | Storage sedimentation (Cambridge, MA) | Microscreening (Philadelphia, PA) |
|---|---|---|---|---|
| Total solids | mg/l | 18,900 | 126,900 | 8,660 |
| Suspended solids | mg/l | 17,400 | 110,000 | 7,000 |
| Total volatile solids | mg/l | 9,150 | 57,500 | 2,520 |
| Volatile suspended solids | mg/l | 8,425 | 41,400 | 1,755 |
| BOD | mg/l | 2,200 | 12,000 | - |
| TOC | mg/l | 7,250 | 16,200 | 1,032 |
| Dissolved organic carbon | mg/l | 55 | 946 | - |
| Total phosphorus (as P) | mg/l | 109.1 | 293.4 | 11.5 |
| Total kjeldahl nitrogen (as N) | mg/l | 56 | 28 | 46 |
| Ammonia (as N) | mg/l | 4.1 | 3.2 | - |
| $NO_2$ (as N) | mg/l | 0.15 | 0.4 | - |
| $NO_3$ (as N) | mg/l | 1.7 | 0.5 | - |
| Specific gravity | -- | 1.015 | 1.06 | 1.05 |
| pH | -- | 6.4 | 5.7 | 7.4 |
| Total coliforms | #/100 ml | - | 210,000,000 | - |
| Fecal coliforms | #/100 ml | - | 2,800,000 | - |
| Fuel value | cal/gm | - | 2,721 | 1,791 |
| PCB's | µg/kg dry | 47 | 6,570 | ND |
| pp'DDD | µg/kg dry | ND | ND | ND |
| pp'DDT | µg/kg dry | ND | 170 | ND |
| Dieldrin | µg/kg dry | 20 | 58 | ND |
| Zinc | mg/kg dry | 799 | 946 | 1,189 |
| Lead | mg/kg dry | 2,063 | 1,261 | 2,448 |
| Copper | mg/kg dry | 201 | 757 | 200 |
| Nickel | mg/kg dry | 159 | 126 | 289 |
| Chromium | mg/kg dry | 243 | 260 | 52 |
| Mercury | mg/kg dry | 2.7 | 0.01 | 2.1 |

ND = None Detected

TABLE 5. CHARACTERISTICS OF CSO SLUDGES FROM PHYSICAL/CHEMICAL TREATMENT PROCESSES (12)

| Parameter | Units | Screening/ dissolved-air flotation (Racine, WI) | Dissolved-air flotation (Milwaukee, WI) | Dissolved-air flotation (San Francisco, CA) |
|---|---|---|---|---|
| Total solids | mg/l | 9,769 | 42,700 | 24,000 |
| Suspended solids | mg/l | 8,433 | 41,900 | 22,500 |
| Total volatile solids | mg/l | 3,596 | 11,350 | 9,400 |
| Volatile suspended solids | mg/l | 3,340 | 10,570 | 8,850 |
| BOD | mg/l | 1,100 | 3,200 | 1,000 |
| TOC | mg/l | 260 | 6,050 | 1,600 |
| Dissolved organic carbon | mg/l | 60 | 340 | 67 |
| Total phosphorus (as P) | mg/l | 39.2 | 149 | 166 |
| Total kjeldahl nitrogen (as N) | mg/l | 112 | 517 | 375 |
| Ammonia (as N) | mg/l | 6.3 | 12.5 | 7.5 |
| $NO_2$ (as N) | mg/l | <0.1 | <0.1 | 0.02 |
| $NO_3$ (as N) | mg/l | <0.1 | <0.1 | 0.1 |
| Specific gravity | -- | 1.01 | 1.07 | 1.014 |
| pH | -- | 6.9 | 7.2 | 5.2 |
| Total coliforms | #/100 ml | 40,000 | 6,400,000 | 6,300,000 |
| Fecal coliforms | #/100 ml | 1,400 | 220,000 | 17,000 |
| Fuel value | cal/gm | 1,961 | 1,359 | 1,950 |
| PCB's | µg/kg dry | 603 | 775 | 113 |
| pp'DDD | µg/kg dry | ND | 225 | 29 |
| pp'DDT | µg/kg dry | ND | TR | 96 |
| Dieldrin | µg/kg dry | 24 | 9 | 192 |
| Zinc | mg/kg dry | 1,638 | 855 | 708 |
| Lead | mg/kg dry | 1,023 | 164 | 1,583 |
| Copper | mg/kg dry | 481 | 248 | 367 |
| Nickel | mg/kg dry | 251 | 173 | <83 |
| Chromium | mg/kg dry | 251 | 150 | 1,667 |
| Mercury | mg/kg dry | 2.3 | 2.1 | 3.9 |

ND = None Detected TR = Trace (<0.2 µg/l on wet basis)

TABLE 6. CHARACTERISTICS OF CSO SLUDGES FROM BIOLOGICAL TREATMENT PROCESSES (12)

| Parameter | Units | Contact stabilization (Kenosha, WI) | Trickling filter (New Providence, NJ) | |
|---|---|---|---|---|
| | | | primary | secondary |
| Total solids | mg/l | 8,527 | 2,010 | 25,500 |
| Suspended solids | mg/l | 8,300 | 1,215 | 25,070 |
| Total volatile solids | mg/l | 5,003 | 1,120 | 15,500 |
| Volatile suspended solids | mg/l | 5,225 | 780 | 14,770 |
| BOD | mg/l | 1,700 | 728 | 11,200 |
| TOC | mg/l | 3,400 | 700 | 13,000 |
| Dissolved organic carbon | mg/l | 29 | 220 | 710 |
| Total phosphorus (as P) | mg/l | 194 | 22 | 436 |
| Total kjeldahl nitrogen (as N) | mg/l | 492 | 65 | 6 |
| Ammonia (as N) | mg/l | 42 | 9 | 180 |
| $NO_2$ (as N) | mg/l | 0.055 | 0.02 | 0.02 |
| $NO_3$ (as N) | mg/l | 0.065 | 0.11 | 0.09 |
| Specific gravity | -- | - | 1.005 | 1.013 |
| pH | -- | 7.9 | - | - |
| Total coliforms | #/100 ml | 1,200,000 | 3,400,000 | 1,000,000 |
| Fecal coliforms | #/100 ml | 79,000 | 44,000,000 | 1,300,000,000 |
| Fuel value | cal/gm | 3,446 | 3,585 | 3,583 |
| PCB's | µg/kg dry | 767 | 547 | - |
| pp'DDD | µg/kg dry | 93 | ND | - |
| pp'DDT | µg/kg dry | TR | ND | - |
| Dieldrin | µg/kg dry | 88 | ND | - |
| Zinc | mg/kg dry | 7,154 | 697 | 1,294 |
| Lead | mg/kg dry | 528 | <498 | 353 |
| Copper | mg/kg dry | 1,454 | 995 | 1,020 |
| Nickel | mg/kg dry | 528 | 995 | 784 |
| Chromium | mg/kg dry | 1,278 | 746 | 2,471 |
| Mercury | mg/kg dry | 2.6 | 100.5 | - |

ND = None Detected TR = Trace (<0.2 µg/l wet basis) solids are then not associated with waste activated sludge but are present in CSO sludges. In addition, CSO sludges have not been stabilized and therefore a comparison to undigested residues is valid.

A summary of generalized sludge characteristics including CSO sludges, raw primary and digested primary is included in Table 7. The data presented has been drawn from several sources, as indicated. Wide ranges have been presented because of the extreme variation in values obtained from the different references. However, it is understood that the large differences are due mainly to large variations in influent wastewater characteristics and treatment plant efficiencies throughout the country. There is also a large variation in values indicated for the CSO sludges due to the different treatment techniques utilized and the many other variables previously mentioned. Therefore, it is necessary to provide only broad comparisons between the dry-weather primary sludge and the CSO sludges.

The table indicates that the potential volume of CSO sludges exceeds the estimated primary sludge volume. However, the pounds of dry solids of the two residues is much more comparable due to the higher solids concentration in raw primary sludges. This difference in solids concentration is an important aspect when considering CSO sludges and is mainly due to the very dilute backwash residue produced from the screening processes which treat raw CSO. Additional thickening is required to reduce the volume of CSO sludge to be either further stabilized or transported. This is desirable since an increase in solids of 1% can halve the total volume being handled.

In addition to having a low solids content, the percent volatile solids in CSO sludges is significantly lower than that found in most raw primary sludges. The highest value obtained for CSO sludges was associated with the biological type of treatment, as expected. Even with this input, the volatile percentage was significantly lower for CSO sludge than for raw primary. Furthermore, the values were much more comparable to already digested primary solids. Therefore, lower effective removals of volatile solids are expected as the microbial mass is diminished due to a smaller feed source.

Comparison of other parameters indicate that there are some differences, but that the ranges of concentrations overlap in most categories. General observations indicate that the total nutrient concentrations are generally lower in CSO sludges than in raw and digested primary sludge. Fecal coliform numbers are also lower possibly due to dilution of influent from the rainfall. No comparable data regarding pesticide content was available for raw CSO sludges and raw primary, however, concentrations in digested primary were somewhat higher than those detected in raw CSO sludges. Metals concentrations in all of the sludge types showed extremely high variations. The concentration of metals in CSO sludges ranged close to the values obtained for raw primary residue. The concentration of nickel was somewhat higher for CSO sludges, however, lead concentrations did not reach the high levels reported for some raw primary sludges.

One significant difference between CSO sludges and raw primary which is not apparent from Table 7, is the high grit content of most CSO sludges. This

TABLE 7. CHARACTERISTICS OF CSO AND PRIMARY SLUDGES

| Parameter | Units | CSO Sludges* | Raw primary sludge | Digested primary sludge |
|---|---|---|---|---|
| Volume | cu m/year | $156 \times 10^6$ | $60.9 \times 10^6$ | $30.3 \times 10^6$ |
| Dry solids | metric ton | $1.67 \times 10^6$ | $2.88 \times 10^6$ (3) | $2.88 \times 10^6$ |
| Sludge production | $m^3/Mm^3$ | 2,000 - 200,000 | 2,440 - 3,530 (4) | 500 (2) |
| TS | percent | 0.3 - 6(1.04) | 2 - 7(4) (1) | 6 - 12(10) (1) |
| Volatile solids | % of TS | 26.6 - 48.4 | 60 - 80 (1) | 30 - 60 (1) |
| Phosphorus (as P) | mg/kg | 2,875 - 7,450 | 3,500 - 12,200 (1) | 4,700 - 13,900 (1) |
| TKN | mg/kg | 1,100 - 13,000 | 15,000 - 40,000 (1) | 6,700 - 54,000 (1) |
| Ammonia | mg/kg | 80 - 750 | -- | 3,000 - 13,000 (2) |
| Fecal coliform | #/100 mls | $1.4 \times 10^3 - 2.8 \times 10^6$ | $11 \times 10^6$ (3) | $0.4 \times 10^6$ (3) |
| PCB's | µg/kg | ND - 6,570 | -- | ND - 10,500 (3) |
| pp'DDT | µg/kg | ND - 170 | -- | ND - 1,000 (3) |
| Dieldrin | µg/kg | ND - 192 | -- | 100 - 2,000 (3) |
| Zinc | mg/kg | 697 - 7,154 | 900 - 8,400 (5) | 72 - 12,800 (5) |
| Lead | mg/kg | 164 - 2,448 | 150 - 26,000 (5) | 9,000 - 22,000 (5) |
| Copper | mg/kg | 200 - 2,454 | 200 - 1,740 (5) | 290 - 1,360 (5) |
| Nickel | mg/kg | 83 - 995 | 44 - 740 (5) | 20 - 1,500 (5) |
| Chromium | mg/kg | 52 - 2,471 | 66 - 3,100 (5) | 44 - 7,200 (5) |
| Mercury | mg/kg | 0.01 - 100.5 | 1.2 - 3.4 (5) | 1.4 - 7.0 (5) |

* All CSO values referenced from Tables 3, 4 and 5.

(1) Superscript indicates reference number attached.

## REFERENCES FOR TABLE 7


1. Metcalf & Eddy Inc., Wastewater *Engineering: Collection, Treatment, Disposal*, McGraw-Hill Book Company, 1972, p. 586, Table 13.2.

2. Reed, S., Wastewater Management by Disposal on the Land, Cold Regions Research and Engineering Laboratory, May 1972, Tables B-1 - B-4.

3. Farrell, J. B., Overview of Sludge Handling and Disposal Proceeding Pretreatment and Ultimate Disposal of Wastewater Solids, Rutgers University, May 21-22, 1974, p. 1-22.

4. U.S. EPA Process Design Manual for Sludge *Treatment and* Disposal., EPA 625/1-74-006, p. 3-1.

5. Blakelee, P.A., Monitoring Considerations for Municipal Wastewater Effluent and Sludge Application to the Land, Proceedings of the Joint Conference on Recycling Municipal Sludges *and Effluents on* Land, Champaign, IL, p. 183-198.

high concentration of heavy particulate matter is caused by the high velocity scouring of materials which accumulate in sanitary sewers and the lack of preseparation of grit before treatment. Primary sedimentation is generally preceded by grit removal which usually separates materials that settle faster than 5 fpm or have a specific gravity greater than 2.65. Without grit removal for CSO residues, the characteristics of the sludge are significantly affected by the presence of this grit. Special handling methods are necessary to stabilize and dewater these materials since most traditional techniques are not designed to take the heavy loading. This is especially true when transporting the sludges in a liquid form. The heavy particulates will tend to settle to the bottom of sewers or tanks and enhance putrefaction. This situation may be extremely difficult to remedy and should be considered before determining handling methods.

Another aspect of CSO sludge which is difficult to quantify is the intermittent nature of sludge production. This factor itself presents problems when compared to primary sludges which are produced daily with approximately the same volume and characteristics. The intermittent nature of the sludge production indicates that holding and pumpback of the material is necessary to equalize the flows, however, holding the sludge may cause significant changes in its characteristics, and create odor and septicity problems. If equalization is not possible, then the sludge handling method must be flexible enough to accept shock loadings from wet weather sludge or a separate facility capable of intermittent operation must be constructed and utilized. It is therefore evident that the problems associated with handling CSO sludges are unique and difficult to solve. The potential volumes of sludges and the accumulation of pollutants including solids, organics, heavy metals etc. generated by the treatment of combined sewer overflows are formidable. The relatively dilute nature and low volatile solids content of the sludges along with their intermittent generation create a situation significantly different from that encountered when dealing with raw primary sludges. These differences and proposed techniques for dealing with them will be considered in the following sections of the report. The evaluations of various alternatives for handling these residuals are developed to assist in arriving at an assessment of the impact, effort required, and resources needed, if full-scale treatment of CSO discharges on a national level is to be implemented.

# SECTION V

## EFFECT OF HANDLING CSO TREATMENT RESIDUALS BY BLEED/PUMP-BACK TO THE MUNICIPAL DRY-WEATHER PLANT

One of the possible methods for handling CSO treatment residuals is bleed/pump-back of these materials to the dry-weather treatment plant. These sludges may be either the dilute residuals themselves or the supernatant liquor which was generated by on-site dewatering. In addition, the return of residuals can affect either the total dry-weather treatment plant or the sludge handling facilities, or both, depending upon the nature of the return system. Full evaluation of the effect of residual bleed/pump-back can then be broken down into several sections:

1. Effect of bleed/pump-back of dilute residuals on the treatment plant.
2. Effect of bleed/pump-back of residuals from on-site dewatering on the treatment plant.
3. Effect of bleed/pump-back of dilute residuals on the sludge handling facilities.
4. Effect of bleed/pump-back of residuals from on-site dewatering on the sludge handling facilities.

To accomplish the evaluation, it is necessary to consider the effect of bleed/pump-back on the design characteristics of the dry-weather treatment plant. The following aspects are to be studied:

a) Hydraulic overload
b) Solids overload
c) Organic and inert solids overload
d) Toxicity to treatment
e) Treatment efficiency
f) Effluent quality (treatment system only)

These individual considerations have been studied with regard to the bleed/pump-back of residuals to the various parts of the treatment plant. The results of the evaluation are discussed individually in this section of the report.

### TRANSPORT CONSIDERATIONS

It is apparent that bleed/pump-back of the sludges to the dry-weather treatment plant offers the simplest solution to handling CSO sludges. This alternative utilizes existing transport facilities, a centralized treatment location and trained dry-weather treatment plant staff to provide handling. However, there are inherent problems involved in bleed/pump-back, due to both the general design of combined sewers and the high grit content of CSO sludge. This section briefly presents some of the problems involved in bleed/pump-back. The sections which follow assume that the CSO sludge has been satisfactorily bled/pumped-back to the plant and the calculations establishing the effect of the CSO sludges continues from that point.

One of the main problems with bleed/pump-back is that combined sewers cannot be designed to provide needed velocity for scouring heavy particles during dry-weather conditions. The WPCF Manual of Practice No. 9 states that, "It is rarely possible to design combined sewers with adequate self-cleaning velocities at minimum dry-weather flow if the capacity of the sewer also must be adequate for stormwater runoff. Hence, combined sewers often are subject to deposition during dry weather and are dependent on frequent rainfall for flushing" (15).

Calculations of the possible velocity in an existing combined sewer verifies that statement. Using Camp's formula for calculation of the velocities required to transport sediments, the velocity in a 0.97 m x 1.27 m (38" x 50") interceptor required to transport a grit particle 0.2 mm in diameter with specific gravity of 2.65 was 0.87 m/s (2.87 fps). The interceptor was designed at a slope of 0.06 m/100 m (0.06 ft/100 ft) and velocity flowing full was calculated to be 0.7 m/s (2.31 fps) which would scour particles less than 0.13 mm. Typical grit chamber design can remove particles of 0.2 mm or more at velocities of 0.305 m/s (1 fps). So these calculations indicate that there would be significant accumulation of particulates greater than 0.13 mm in this sewer under dry-weather flow conditions.

It must then be recalled that there are high concentrations of grit within the CSO sludges. This is due in part to grit and associated stormwater infiltration through leaky joints in the sanitary sewers which is flushed to the CSO treatment site during storm flow. Replacing the gritty sludge in the downstream line will cause this accumulation to recur in the sewers under most conditions. The problem is augmented by the fact that it is desirable to equalize the flow to the treatment plant. Therefore, sludge bleed/pump-back would ideally occur at low flow, low velocity time periods, causing even greater solids deposition. Once the solid materials have collected on the sewer bottom, flow capacity usurpation and septicity and odor problems can occur. These nuisances can create premature flooding and pollution causing overflows, public relations problems and dry-weather treatment plant operations difficulties. The septic solids can exert a significant oxygen demand on the raw sewage flow and cause excessive oxygen requirements at the treatment plant.

In conclusion, problems of bleed/pump-back of the sludge are therefore difficult to overcome and should be considered prior to recommendation of this alternative for handling CSO sludges. If sufficient carrying velocity is not available, the excessive grit deposition can cause a myriad of secondary problems. Careful examination of the individual sewer interceptors to be used for bleed/pump-back and knowledge of the sieve analysis and density or particle settling velocities of the CSO sludge will be necessary in order to determine if bleed/pump-back will cause deposition of solids in the interceptors.

## TREATMENT CONSIDERATIONS

### General

In order to accurately assess the impact of bleed/pump-back of CSO residuals on any portion of the treatment plant, it is necessary to calculate the effects for each individual site. However, it is desirable to approximate the effects of bleed/pump-back of CSO sludges on a generalized basis to establish what aspect of bleed/pump-back is limiting and when this technique might be a viable handling method for CSO sludges. Therefore, it is necessary to make a series of assumptions in the approach to establishing the effect of bleed/pump-back of CSO sludges or their dilute residuals on the dry-weather treatment plant and the existing sludge handling facilities. Among the factors to be considered are the type and degree of treatment utilized, the effect of diurnal flow variation and contaminant strength, the CSO sludge characteristics, the percent of CSO area contributing sludge to treatment, etc.

### Degree and Type of Treatment Used and Effluent Discharge Requirements

It is essential to know the type of treatment processes utilized at the dry-weather treatment plant in order to establish the effect of the bleed/pump-back of both sludges and residuals. It is also important to determine the type of sludge handling facilities used for dewatering and then consider the effect of CSO sludge bleed/pump-back on this portion of treatment individually.

U.S. Public Law 92-500 (1972) requires that by July 1, 1977, publicly owned (municipal) treatment works provide a minimum of secondary treatment. Moreover, effluent discharge limitations for suspended solids and BOD have been promulgated at 30 mg/l (monthly average) and 45 mg/l maximum (seven day average). Therefore, for purposes of this discussion, it may be assumed that the dry-weather treatment facilities to which CSO treatment residuals are to be bled/pumped back will provide a minimum of secondary treatment. Furthermore, for purposes of evaluating the effect of the CSO treatment residuals bleed/pump-back on dry-weather treatment efficiency, the effluent discharge limitations promulgated will be used. A schematic diagram of a typical activated sludge secondary treatment plant is shown in Figure 3. The end products of waste treatment, namely, treated effluent and residual sludge solids, must be disposed of efficiently and economically. Therefore, the dry-weather facility consists of two systems, the waste treatment system and the sludge handling system. The elements comprising the waste treatment system are shown in Figure 3.

Referring to Figure 3, the process elements making up the treatment portion of a municipal pollution control facility are grit removal, primary sedimentation, biological oxidation and final clarification. Various dry weather design and operational parameters associated with these process elements are summarized in Table 8 and were obtained from the literature (16, 17, 18, 19). These criteria are among those that will be used in the evaluation of the effect of the CSO treatment residuals bleed/pump-back to dry weather treatment facilities with regard to hydraulic, solids and organic overload as well as treatment efficiency.